Mitigating temperature increases in high lot density sub-tropical residential developments

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This is the author-manuscript version of this paper. Published in:

Luxmoore, David A. and Jayasinghe, M. Thishan R. and Mahendran, Mahen (2005) Mitigating temperature increases in high lot density sub-tropical residential developments . *Energy and Buildings* 37 pp1212-1224.

Abstract: Residential developments built with houses that use passive design features can have significantly reduced energy requirements for thermal comfort. In the context of global warming, this can reduce greenhouse gas emissions. The current trend toward higher lot density in residential developments and the resulting increase in thermal mass increases the associated heat island effect. Designers of future residential developments face the dual challenges of heat island impacts and any future global warming. Resource efficient house designs combined with approaches that mitigate the outdoor heat load must be considered and addressed from the design of the initial subdivision layout. Some land sub-division and house design initiatives are proposed for sub-tropical south east Queensland, Australia. Computer simulations that account for heat island and global warming effects are used to estimate the indoor thermal performance of display houses for current climate conditions and scenarios that may occur in the future. A north-south orientation of narrow building lots combined with high albedo house surfaces and the increased use of shade trees can significantly reduce the heat island effect of high density residential developments. The cooling requirements of houses with high energy rating (5 star) are increasingly superior to those with low rating (3.5 star) in scenarios of global warming.

1. Introduction

Properly planned houses should be thermally comfortable throughout the day for as many days as possible every year. In the light of global warming, it is ideal to achieve these conditions with passive means at the design stage, thus avoiding high energy consuming mechanical means of providing thermal comfort such as air conditioning. This will not only save energy, but will also support sustainable residential development, which requires the designers to satisfy the needs of today's users without compromising the ability of future generations to meet their own needs. Escalating land prices, the cost of providing infrastructure and the need to control urban sprawl will require maximising the number of detached houses in a given area when multi-storey buildings incorporating a large number of units are not the preferred option. This results in a higher lot density and closely spaced houses which will pose more challenges to the designers of sustainable passive houses.

The design of thermally comfortable houses should start with subdivision layout planning which allows for favourable orientations for house lots given the topography, vegetation and other constraints. On such lots, the house designers can concentrate on the spatial arrangements, roof and wall insulations, window locations and style, shading devices, etc. to suit the local climatic conditions and wind directions. However, there are increased challenges with global warming since a house planned to be thermally comfortable with the present climatic conditions may become uncomfortable in the future. Today's houses should be providing shelter and thermal comfort for further 100 years. It is predicted that the Earth's average temperature could rise by 1.4^{o}C to 5.8^{o}C by year 2100 (AGO, 2002) if the nations around the world do not act to control greenhouse pollution. Even if carbon dioxide gas emissions are stabilised at the present level, the temperatures will continue to increase due to the low reabsorption rate of carbon back into natural systems.

It is acknowledged that there are annual and seasonal variations which can realise temperature fluctuations of 7 degrees or even more. This when combined with the fact that the climatic data sets have only been continuously reliable for a relatively short time (10 years in some climatic zones in Australia) does not allow for conclusive results from any of the simulations, processes or logic contained herein. Trends however can be identified which support the objective of this paper.

In high lot density housing developments, a large portion of the land would be covered with roofs, paved surfaces and roads, thus reducing the location for vegetation. This will lead to a heat island where the outdoor temperatures of the housing development will be higher than that before the development. For example, the maximum temperature of metropolitan areas of Los Angeles and Washington DC have risen by 2-2.5^{o}C during the past 70 to 100 years. It is also important to note that the minimum temperatures were also similarly affected thus indicating a transformational rise in temperature of the built up areas when compared with the nearby rural areas (Akbari et al., 2001). Thus global warming will be further aggravated by the heat island effects.

It was reported by Sailor and Pavlova (2003) that 1^{o}C increase in the ambient temperature could increase the residential electricity consumption by 2-4% with air-conditioned houses in the USA. Future temperature increase may shift even the owners of many passive houses to install air conditioners thus leading to a many fold increase in the electricity consumption and its associated greenhouse gas emissions. It will be important to minimise the chances for this increasing trend towards air conditioning in houses by implementing measures that would minimise impacts of the temperature rises that are predicted in the future.

Therefore, new land sub-division layouts should concentrate not only on desirable orientations for the blocks and the road networks, but also the mitigation of heat island and global warming effects. This paper describes the required concepts for such an approach developed for sub-tropical climatic conditions prevailing in south east Queensland, Australia, supported by computer simulations to quantify the probable effects on the indoor temperatures of a selected house.

2. Objective and Research Methods

The main objective of this research is to present improved land sub-division initiatives that can be coupled with improved energy efficient housing from passive design. These initiatives will assist in mitigating the heat island and global warming effects and reduce the impact of these warming effects on the thermal performance of a house in sub-tropical climatic conditions. The following methods are used in this research:

1. The main characteristics of houses and suburban developments in sub-tropical South East Queensland area are identified along with generally adopted passive house design techniques and energy rating programs for house assessments.
2. The successful strategies that have been used for heat island mitigation are presented and applied to high lot density residential developments.
3. The effects of temperature increases on the thermal performance of selected display houses are then assessed using computer simulations with available and modified climatic data.

3. Climatic conditions and passive houses

The climatic conditions prevailing in the suburban areas of greater Brisbane (latitude of 27.7^{o} S) in South East Queensland, Australia can be considered as sub-tropical with mild to hot summers and mild winters. The spring and autumn seasons are quite pleasant with a moderate diurnal temperature range. The solar radiation intensities are high even during the winter in clear sky days.

The climatic data is presented in Table 1 for Ipswich (a city which adjoins the south western outskirts of Brisbane city) where Springfield Lakes, a large housing development for about 20,000 houses, is presently being constructed. It is within this housing development that the display houses selected for simulations have been designed and constructed. The data in Table 1 indicates a winter monthly minimum temperature as 8.4^{o}C and summer monthly maximum as 30.0^{o}C. The average humidity also remains below 15 g/kg of air throughout the year which can create day time low humidity values of 50-60% during the warm summer days. Table 1 also gives the neutrality temperatures for each month which is used to determine the thermally comfortable conditions.

As the winters are relatively mild and only last over a 2-3 month period, the traditional houses known as *Queenslanders* were and elevated construction on posts with timber walls and iron sheet roofs which proved effective for the warm humid summers. However, a large percentage of modern houses are now constructed as slab on ground with brick veneer walls and tiled roofs. Even during winter, the daytime temperatures rise to about 20^{o}C on most of the days. Therefore, very little heating is required for thermal comfort during winter in well planned houses. Generally, houses are not provided with central heating and people may use portable heaters only for few days of low temperatures. However, installation of air conditioners is gradually gaining popularity since there are four months (December to March) that can have high daytime average temperatures. Such temperatures coupled with intense solar radiation on clear sky days can make the indoors quite uncomfortable unless the houses are optimised using passive design.

Table 1: Climatic data and the corresponding neutrality temperatures for Ipswich (BERS, 2003)

Month	Maximum temperature ^{o}C	Minimum temperature ^{o}C	Mean monthly temperature ^{o}C	Neutrality Temperature ^{o}C	Average Humidity (g/kg of air)
January	30.0	20.0	25.0	25.4	14.7
February	29.1	19.2	24.1	25.0	13.4
March	28.5	19.9	24.2	25.0	13.6
April	26.0	14.7	20.4	23.9	10.4
May	24.5	9.6	17.1	22.9	7.7
June	20.4	8.4	14.4	22.1	6.9
July	21.3	8.4	14.9	22.2	7.1
August	21.5	8.4	15.0	22.2	6.8
September	23.1	12.3	17.7	23.0	8.9
October	24.6	14.0	19.3	23.5	9.9
November	27.8	17.5	22.6	24.6	11.7
December	28.3	19.7	24.0	25.1	13.5

The current trend in South East Queensland is to build detached houses on small (300 m^2) to large blocks (1000 m^2) with three to four bed rooms although the average population density per household is only 2.8 (AusStats, 2003). The majority of these houses are single storey since two storey houses cost more per square metre mainly due to additional structural and scaffolding costs. However, in some residential developments, blocks as small as 200 m^2 have been created although a more acceptable minimum is about 300 m^2. In new housing developments, the road network generally consists of 6-8 m wide access roads connected to collector roads of 8-10 m carriageway width. A concrete path of 2m width is provided for pedestrian access, generally only on one side of the road.

Since South East Queensland is located south of the tropic of Capricorn, the sun movement is primarily to the north except for a few weeks during the summer. Therefore, it is usually preferred to have the access roads in approximately east-west direction which will result in houses being oriented across the block to present to the street. On larger blocks, this allows the long axis of the house also to stand east-west, giving good solar access from the north while minimising hot summer exposure to the “shorter” east and west ends of the house.

Generally, east-west roads also work to the advantage of small narrow blocks which require the house to orientate along the longer north-south axis. This results in a narrow exposure to the north and potentially larger exposure of east-west walls to direct summer sun. With high lot density and narrow blocks, adjoining houses are very close or constructed on the side boundaries. This then provides shading effects on adjoining houses and removes a significant negative impact from eastern and western summer sun. Additional protection can be provided by selecting the garage and laundry facing west. It is still most desirable to keep the main living area at the northern end of the house. This means, certain advantages can be gained for passive houses by sub-dividing the land with approximately east-west roads and narrow blocks with their longer axis approximately north-south. It is generally accepted that the advantage of northerly aspect for better winter sun penetration requires side boundaries on narrow lots to remain within 20 degrees either side of true north.

When passive houses are designed, they should combine both thermal efficiency and functionality. Various state government departments and local authorities in South East Queensland are actively promoting initiatives and recommendations for sustainable housing development (SEQROC, 2003 and DOH, 2003). The energy efficiency issues are handled by allocating energy ratings for the houses using appropriate software. These programs are able to assess the thermal performance of a house at the given location based on existing climatic data. They consider that the house is maintained at certain desirable thermal conditions and evaluate the energy required to maintain these conditions. Based on the predicted energy required to maintain thermal comfort, star ratings are allocated with rating values from 1 to 5. A rating of five is considered as the most desirable. It should be noted that these energy rating programs do not allow for effects of any probable climatic changes that may occur in the future since the simulations are based on past climatic data. Some local authorities in South East Queensland already require an energy rating minimum of 3.5 for new houses, using the accepted national rating programs.

Apart from Government, other information sources are available for designing passive houses, with one of the best being the *Your Home* project undertaken by the Australian Greenhouse office (AGO, 1997). The thermal performance of a house will be greatly improved with the adoption of these techniques in an appropriate manner. Their recommendations for sub-tropical climates can be briefly presented as the following:

- the use of reflective and bulk insulation
- use of light weight construction that can cool quickly
- maximising the external wall areas for more windows which will allow for better ventilation
- site exposure to breezes
- shading the house during the summer while allowing passive solar access in winter months
- shading all east and west walls and windows especially in summer.

These various guidelines and methods indicate just some of the abundance of information on the design principles for passive houses in Australia. However, the availability of this information has not been converted into producing thermally efficient houses as found by a research study carried out in 2001 at a leading housing development, about 30 km north of Brisbane. The study found that about 80% of the houses were built with an energy rating of only 1 or less (Tucker et al., 2003). This indicates that there is a considerable gap between the knowledge and the application. These houses are also likely to be air-conditioned in the future due to the increasing affordability of air conditioners and the low cost of electricity. The study also found that the extra cost of improving these houses up to an energy rating of five would cost only about 2% extra based on the total cost of the house.

4. Impact of high lot density residential developments

High lot density residential developments consisting of detached single storey houses have severe adverse effects on the existing vegetation and natural drainage. They also create the phenomenon known as heat islands. These effects are discussed briefly in order to highlight the need for improved land sub-division approaches.

4.1 Impact on vegetation

High lot density residential developments require clearing of most of the existing vegetation for the construction of infrastructure facilities and houses. Generally, complete re-vegetation is required and this is hampered by the reluctance of planting trees close to the houses, especially on small blocks of land. The vast majority of reintroduced vegetation is of small to medium height and is planted away from houses. Dedicated park areas, quite often gully lines, are the only areas where existing vegetation of any significance is preserved.

4.2 Impact on drainage

Residential developments with roads and single storey houses replace the permeable land with impervious roofs and paved surfaces. After rain and storm events, this increases surface runoffs and demand on stormwater systems and natural drainage paths. It also minimises the ground water recharge which may affect the size and quality of new and existing vegetation.

4.3 Creation of heat islands

A modern high density residential housing development would have a large number of roofs and many access roads. During hot summer days, dark coloured roofs absorb solar radiation and in turn heat the air near them during summer nights. The same process would also happen with dark coloured roads and other paved areas. It was shown with a detailed experimental study during summer in Tokyo by Asaeda and Ca (2000) that an asphalt paved road could reach a temperature of 50^oC by noon whereas a grass surface reached only 42^oC. Immediately after the sunset, the grass surface cooled down to the ambient 30^oC while the asphalt paved road remained at 38^oC. At midnight, the road was 5^oC higher than the ambient 25^oC. This study also indicated that paved surfaces heat the surrounding air both day and night.

However, vegetation acts in a different way because it releases moisture to the surrounding atmosphere by converting most of the solar radiation to latent heat by evapotranspiration. *Vegetation mitigates heat island effects not by cooling the air, but by warming the air less.* This is a key advantage of vegetation since almost all the surfaces cool down quite well during the night time by loosing heat as long wave radiation to the cool sky. Exposed surfaces with the exception of vegetation become excessively warm during the daytime due to the absorption of solar radiation, and subsequently warm the surrounding air. These were the findings of many studies such as Akbari et al. (1997 and 2001), Simpson (2002) and Dimoudi and Nikolopoulou (2003). These studies indicated an air temperature drop of about 2^oC or more during warm days when plenty of vegetation is available. Vegetation also provides shading effects for the walls from summer sun, thus reducing the surface temperatures of house exteriors. This will also lead to lesser warming of the surrounding air. It should be noted however that the penetration of winter sun should be allowed with strategically located deciduous trees or creepers.

In order to mitigate the heat island effect of roofs, many studies have suggested using light colour roofs which can assist in increasing the albedo; this refers to the hemispherical reflectance of all bands of solar radiation that includes UV, visible and near infrared. For example, a black or grey surface can have an albedo of about 0.1 or less while it could be as high as 0.5-0.7 for a white surface. The figure for vegetation is 0.25-0.3 (Dimoudi and Nikolopoulou, 2003). Similar to vegetation, high albedo roof colours can assist in warming the air less. As found by Berdahl and Bretz (1997), during the daytime, the difference between the surface and ambient temperatures was as high as 50^{o}C with highly absorptive (low-albedo) dark roofs where as the difference was as low as 10^{o}C with less absorptive light coloured surfaces (high-albedo).

It was reported by Taha (1997) that many US and European cities have albedos of 0.15 to 0.20. The same study reports that in mid-latitude warm climatic conditions prevailing in Los Angeles, a temperature drop of 4^{o}C is possible during summer when the albedo is increased from 0.25 to 0.4. Thus high albedo roofs and roads coupled with plenty of vegetation have been identified as the main strategy for reversing the heat island effects by many studies (Bretz and Akbari, 1997, Berdahl and Bretz, 1997, Rosenfeld et al., 1998).

In summary, heat island impacts can be reduced by adopting the following:

- Planting of sufficient numbers of strategically located summer shade trees throughout a high lot density residential development
- Adoption of light coloured roofs and walls for the housing and commercial buildings
- Adoption of light coloured road surfaces
- Reducing, where possible, paved surfaces within both public areas and private housing lots. This would include reducing road pavement widths
- Adoption of appropriate spreading trees to shade road pavements. These should where possible be planted on the northern side of the road reserve to minimise interference with solar access to housing. There would also be a shading advantage for a concrete footpath on the northern side of the road reserve in addition to shading part of the road.

High lot density developments need to promote planting of as many shady trees as possible at appropriate locations taking account of safety and site topography. Housing covenants could be used to promote more and appropriate vegetation within house lots as well as the adoption of lighter coloured roofs and walls.

5. House assessment variables

The initiatives described above for land sub-division would greatly assist well designed passive houses to be free-running; i.e. high energy consuming active means such as air conditioning will not be needed for providing adequate thermal comfort. These houses would rely on either natural flow processes or low energy consuming means such as fans to provide adequate air movement for thermal comfort of the occupants. It will also rely on various passive features to provide thermally comfortable indoor temperatures irrespective of various temperature fluctuations that may arise outdoors. One requirement of free running buildings is the ability of the people to respond to the varying indoor conditions by adjusting various elements like shading devices, windows, clothes and activity levels.

When dealing with a particular climate, it is essential to determine the thermally comfortable conditions for the people who have lived at that location for a considerable duration. The recent trend in defining thermal comfort in free running buildings was to use adoptive comfort models instead of those based on heat balance (Dear and Brager, 2002, Nikolopoulou and Steemers, 2003).

In these adoptive models, the outdoor thermal environment is considered as the input since the weather and seasons exert some influence on the behavioural adaptations to the thermal environment. This is because people generally use the available weather data to decide how to respond to the conditions expected on a particular day. The long term seasonal swings also determine the psychological adaptations in the form of thermal expectations. In this context, it is better to use monthly or weekly weather data than annual values when determining the comfort conditions for people as used by Rajapaksha et al. (2003). For example, in Table 1, the mean monthly values have been used to determine the neutrality temperatures for Ipswich in South East Queensland, Australia. The neutrality temperature (T_n) indicates the value that majority of the people may find quite acceptable within a given climatic condition. It can be determined on the basis of average daily temperature (average of daily maximum and minimum values) over a given period by using the equation, $T_n = 0.31 \times T_o + 17.6$, where T_o is the mean temperature (Szokolay, 1991). This relationship which is based on many comfort survey results, will take account of acclimatization of the people to a given climate. It is assumed that there will not be any heated surfaces, as in un-insulated external walls, close to the occupants to achieve these conditions.

It was reported by Dear and Brager (2002) that about 80% of the people would be thermally comfortable within a band of 7°C about the neutrality temperature in free running buildings. This could be further extended to take account of physiological effect of cooling if sufficient air movement is available. For example, with a neutrality temperature of 25.4°, the desirable upper temperature is 25.4 + 3.5 = 28.9°C. This can be further extended by about 3.0°C as recommended by Szokolay (1991), if a breeze of about 0.6 m/s is maintained indoors either with natural ventilation or fans. The physiological effects of air movement can be taken into account by extending the comfort limits by $6v – v^2$, where v is the indoor air velocity. Similar values have been used by Rajapaksha et al. (2003) to take account of air velocity effects under warm humid conditions. The resulting boundaries of the comfort temperatures are given in Figure 1 for the city of Ipswich located about 30 km south west of Brisbane, Australia.

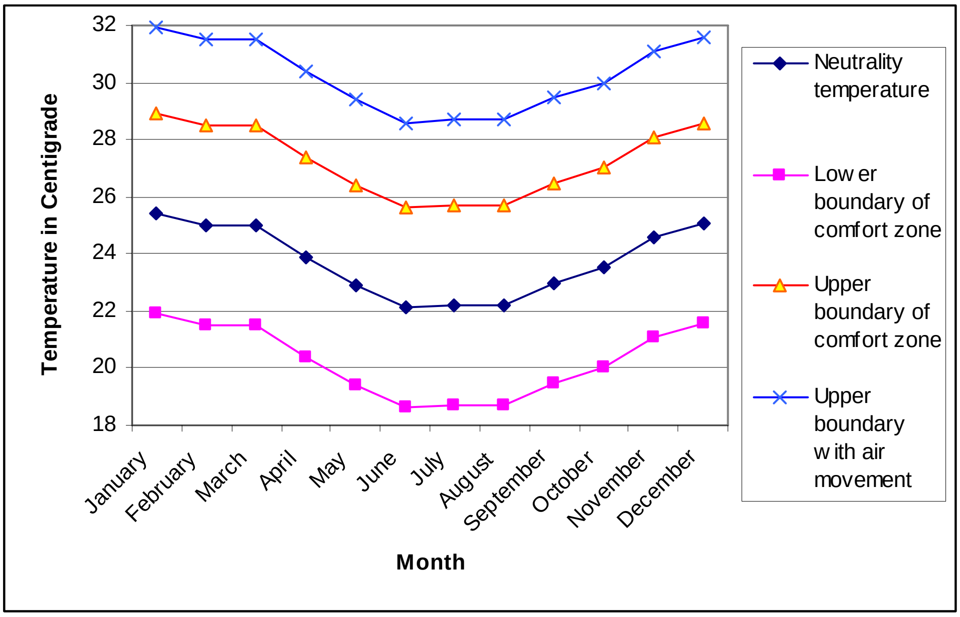


Figure 1: Thermally comfortable conditions for Ipswich on a monthly basis

Once the thermally comfortable temperature range is established, it is possible to compare the indoor temperatures predicted under different climatic conditions that may arise in a high lot density residential development. Figure 1 indicates that a temperature up to 32°C can be considered thermally comfortable during the summer months with some air movement. This is an extremely encouraging result since it may be quite achievable to maintain internal air temperatures of houses below this temperature during most of the summer months. However, if the indoor thermal comfort is achieved with air conditioning, the acceptable variation about the neutrality temperature will be within a quite narrow band (Szokolay, 1991). For a neutrality temperature of about 25^{o}C, indoor air temperature will be maintained below 27^{o}C indicating that the installed air conditioners will be used on most warm summer days.

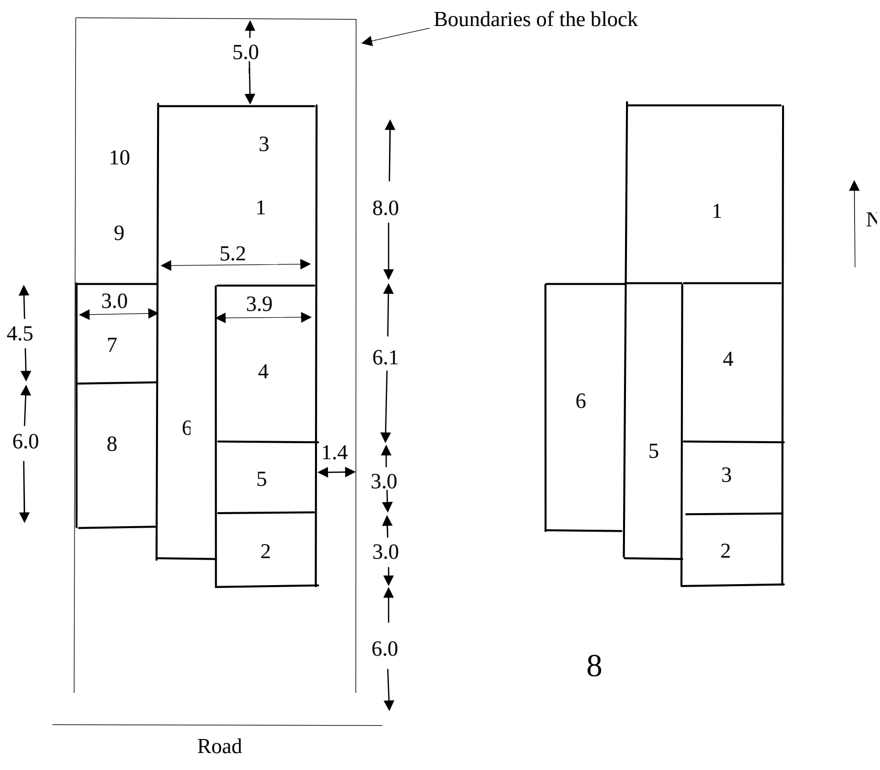
6. Thermal simulations

It is possible to expect many changes to the outdoor temperature in a high lot density housing development. One possibility is that the temperatures would remain at about the present levels. It is also possible to have an increase in temperature due to heat island and global warming effects. These possible variations can affect the indoor temperature of houses in many ways. It is difficult to determine such effects with actual measurements owing to the obvious difficulties in actually creating future climatic variations. In such circumstances, computer simulations are an ideal tool for predicting the probable outcomes. Some of these possibilities are identified as three different cases:

- <u>Case 1</u>: The outdoor temperature remains the same, as assumed by all current national house energy rating programs
- <u>Case 2</u>: The outdoor temperature rises by 2^{o} C from the current levels which may have an adverse effect during summer months
- <u>Case 3</u>: The outdoor temperature rises by 4^{o}C from the current levels

Case 1 may occur even in the face of global warming and heat island effects in a well planned residential development with considerable vegetation and the extensive use of light coloured roofs and walls. Case 2 is more probable even with effort by the developers and occupants to create a higher albedo environment and to maintain a significant green cover with trees. Case 3 may be a possibility if no efforts are made to mitigate the heat island and global warming impacts.

In order to determine the likely indoor thermal performance of a selected display home, the software DEROB-LTH (Appendix B) was used since it allows an accurate representation of the building and can also be used with varying external temperature data files. A nationally accredited energy rating program "Building Energy Rating Scheme" (BERS, 2003) was used to initially determine the energy rating of the chosen display home. This software simulation program which relies on pre-determined annual climatic data files for a given region was also used to undertake simulations for Cases 2 and 3 on two other adjoining display homes.



a. The plan view of the house

1,3 Living, dining and kitchen (5.2 m x 8.0 m)
2. Bed room (3.9 m x 3.0 m)
4. Master bed room with bath (6.0 m x 3.9 m)
5. Bed room (3.9 m x 3.0 m)
6. Entry passage (1.2 m x 10.0 m)
7. Laundry, toilet and bath (3.0 m x 4.0 m)
8. Garage (3.0 m x 6.0 m)
9. Outdoor deck with roof (4.0 m x 2.0 m)
10. Outdoor with pergolas (4.0 m x 2.0 m)

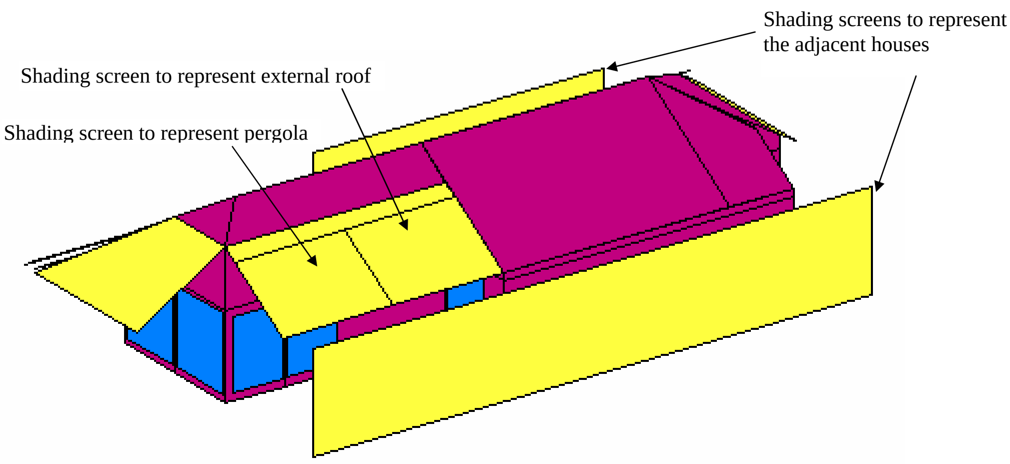
b. The spaces used in the DEROB model

1. Living room (5.2 m x 8.0 m)
2. Bed room (3.9 m x 3.0 m)
3. Bed room (3.9 m x 3.0 m)
4. Master bed room with bath (6.0 m x 3.9 m)
5. Entry passage (1.2 m x 10.0 m)
6. Garage, laundry, toilet and bath (3.0 m x 10.0 m)

Figure 2: The plan view of the display home (Lot 896) and the associated model used for DEROB computer simulations

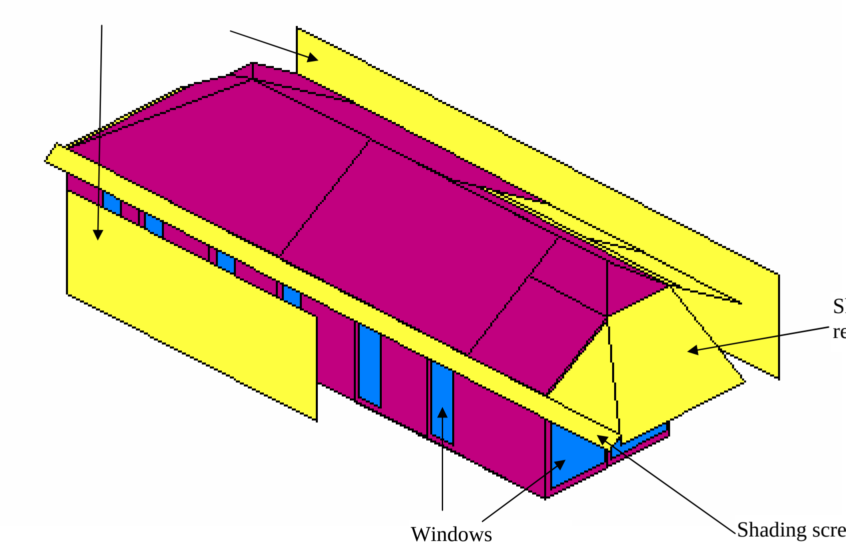
It is not appropriate to directly compare results from both BERS and DEROB as there simulating structure and associated assumptions are different but there are some conclusions that can be drawn from an analysis of their simulation results. DEROB is more rigorous and was adopted to give a more accurate prediction for rooms within a building whereas BERS is focussed on the annual energy use of a whole house.

The display house selected for DEROB simulations was on Lot 896 which was a south facing block in the Springfield Lakes housing development. This house was constructed between October 2003 and March 2004. It has a living and dining area, kitchen, three bedrooms, two bathrooms and a single garage as shown in Figure 2(a). It should be noted that the constructed display house was elevated to minimize the cut and fill involved on the sloping land. Some innovative and new product features used in the display house were not used in this study, allowing it to concentrate more on a typical house that would currently be constructed in South East Queensland.



3a. Observed from the north west direction

Shading screens to represent adjacent houses



3b. Observed from the north east direction

Figure 3: 3D DEROB model of the house

7. Results of computer simulations

The DEROB simulations were carried out with annual climatic data. In order to indicate the likely performance on a hot summer day, a large diurnal variation was selected with a minimum temperature of 17.1^{o}C and the maximum of 31.8^{o}C. Such days are likely to occur over a period of about two weeks in Ipswich with slightly lower maximum temperatures being of frequent occurrence during the summer. This particular day was selected since even when at the maximum temperature, outdoor would still be thermally comfortable in shade when some breeze is present.

The results of the simulations are presented in Figure 4 for Volume 1 (the living room) shown in Figure 2 (b). Volume 1 represents the thermal performance of a typical room with large North facing windows. It also has two small windows facing east which are not shaded by the adjacent house. The window facing west is shaded with pergola. The large percentage of glazing for Volume 1 could be considered a negative passive design element, but was included for the purposes of aesthetics, ventilation, natural lighting and to take advantage of the northerly views. The additional thermal gains and losses over a year were substantially reduced by using low emissivity glass (giving a 5 star rating).

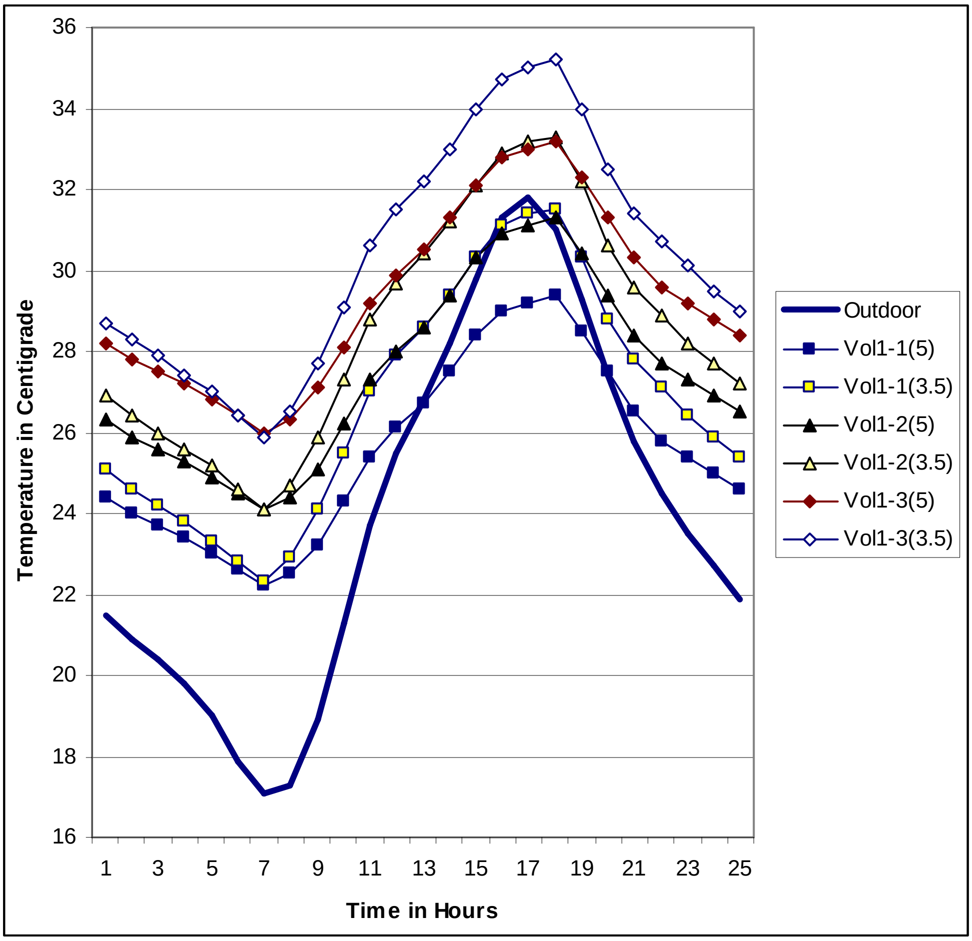


Figure 4: Variation of indoor temperatures for Volume 1 in the house With energy ratings of 3.5 and 5

Figure 4 indicates the indoor temperature of Volume 1 given in Figure 2(b) for both a 3.5 and 5 star house given the current climate scenario (Case 1), 2 degrees warmer (Case 2) and 4 degrees warmer (Case 3) as described in Section 6. The notation Vol 1-2(5) indicates the indoor temperature of Volume 1 for Case 2 with the value within brackets indicating the energy rating. The outdoor temperature indicated is the actual value from the climatic data file for a hot day in January where the diurnal temperature variation was about 15^{o}C. Although DEROB-LTH had been validated for many different climates (Kallblad, 1999, Jayawardana, 2002), the indoor temperatures obtained should not be considered as absolute values occurring in the house since there may be some features that have not been truly simulated. However, such simulation results are quite useful for comparison purposes and to predict the trends where the same house was modelled under different outdoor conditions and with some variations in the model.

The desirable temperature range for January is between 22-32^{o}C as given in Figure 1. It should be noted that about 20% of the occupants may have thermal discomfort at the lower and upper boundaries of this range (Dear and Brager, 2002). Therefore, maintaining the house well within these limits most of the time would be the ideal situation, irrespective of the outdoor temperature. This is the target that should be achieved in houses with a high energy rating of 5.

The results for Case 1 given in Figure 4 show that for a hot day where the outdoor temperature has risen to about 31.8^{o}C, the indoor temperature was maintained well below 32^{o}C for the house with energy rating of 5. The temperature has remained below 32^{o}C for the house with an energy rating of 3.5 as well. This indicates, with no global warming and heat island effects, the house with an energy rating of 3.5 and above can maintain thermally comfortable conditions indoors in warm summer days. However, the house with a rating 5 gives much lower indoor temperatures and hence has lesser need for air conditioning.

When the outdoor temperature increases by 2^{o}C, the house with an energy rating of 5 is still able to maintain a temperature below 32^{o}C throughout the day. In the house with an energy rating of only 3.5, the temperature would rise above 32^{o}C. Therefore, a house with an energy rating of 3.5 or less is likely to perform poorly with future temperature rises.

When the outdoor temperature increases by 4^{o}C, it will be quite difficult even for a 5 star house to have thermally comfortable conditions with passive means and so there may be an increased need for energy consuming active means for thermal comfort.

It can be seen from Figure 5 that the indoor temperature of Volume 2 is lower than the corresponding cases for Volume 1 given in Figure 4. This can be attributed to smaller windows and the shading offered by the adjacent houses. Volume 2 temperatures remain well below 32^{o}C for the house with either 3.5 or 5 energy ratings in Case 1 where the future temperatures are expected to remain at the present values.

However, in the more likely scenario of outdoor temperature rising by 2^{o}C in future (Case 2), the house with an energy rating of 5 is able to maintain a temperature well below 32^{o}C. Thus, the occupants will have many rooms that can offer good thermal comfort. The same option cannot be offered by the house with an energy rating of 3.5.

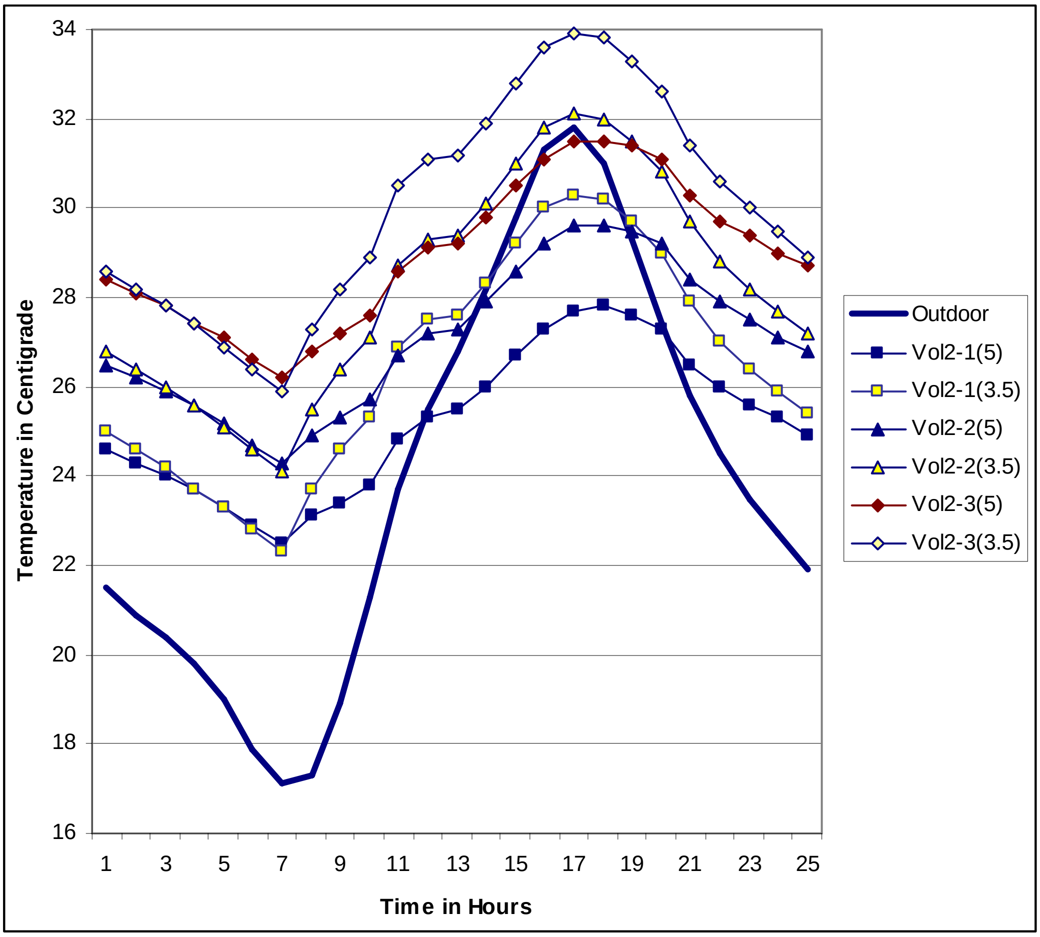


Figure 5: Variation of indoor temperatures for volume 2 in the house

with energy ratings of 3.5 and 5

With a temperature increase of 4^{o}C (Case 3), the volumes under the 3.5 energy rating scenario will not perform satisfactorily but will remain thermally comfortable with the 5 star rating.

The bedroom indicated as Volume 2 in Figure 2(b) faces both south and east and has the advantage of eastern shading from the adjacent house. Once the area facing north is reserved for living, and the garage and laundry are located on the western side, the bedrooms remain facing east and south in a typical narrow lot with general north south orientation. Therefore, narrow blocks with roads in approximately east-west direction can offer some benefits for passive houses, due to this shading effect from adjoining houses.

The BERS simulation results for three different display houses and using three different temperature data files are shown in Table 2. Each of the display homes contained elevated sections to reduce the cut and fill on the sloping sites but this resulted in reduced energy efficiency and a star rating of 4 for each house. Theoretical simulations were also run for each house as a complete slab on ground construction which returned simulated 5 star ratings for each house.

The simulation results show a general trend of a reduction of one rating star for each 2 degree increase in average annual temperature. The heating and cooling energy for the varying conditioned areas within each house are shown in mega joules per square metre (MJ/m2)

DISPLAY HOUSE ON	DESIGN VARIATION	COOLING MJ/m2	HEATING MJ/m2	TOTAL MJ/m2	STAR RATING
		CURRENT TEMPERATURE AVERAGE (case 1)			
LOT 894	elevated	37.3	52.5	89.8	4
	slab	15.9	27.1	43	5
conditioned		**2 DEGREE INCREASE (case 2)**			
area	elevated	159	1.2	160.2	2
144.3 m2	slab	103.6	0.2	103.8	3.5
		4 DEGREE INCREASE (case 3)			
	elevated	229.6	0.3	229.9	1.5
	slab	171.7	0.1	171.8	2
		CURRENT TEMPERATURE AVERAGE (case 1)			
LOT 895	elevated	7	82	89	4
	slab	4.1	56	60.1	5
conditioned		**2 DEGREE INCREASE (case 2)**			
area	elevated	82.3	2.4	84.7	4.5
106.1 m2	slab	52.8	1.2	54	5
		4 DEGREE INCREASE (case 3)			
	elevated	123.6	0.6	124.2	3
	slab	91.3	0.4	91.7	4
		CURRENT TEMPERATURE AVERAGE (case 1)			
LOT 896	elevated	29.6	56.3	85.9	4
	slab	12.6	21.6	34.2	5
conditioned		**2 DEGREE INCREASE (case 2)**			
area	elevated	130.7	1.3	132	3
95.3 m2	slab	87.7	0.1	87.8	4
		4 DEGREE INCREASE (case 3)			
	elevated	199.1	0.5	199.6	1.5
	slab	138.9	0	138.9	3

NOTE - elevated - actual constructed design - elevated with some slab
- slab - same house design but simulated as all slab on ground
- simulations calculated over conditioned areas as shown which includes bedrooms and living areas

TABLE 2 – Results of BERS simulations for Cases 1, 2 and 3 over 3 display homes

Using the nationally adopted climate zones, a star rating of 5 in Ipswich (zone 9) in south east Queensland requires an annual energy use (heating and cooling) of less than 70 MJ/m^2. This leaves the option for setting new lower limits of energy use for star ratings of perhaps 6 (less than 40 MJ/m^2) or 7 (less than 20 MJ/m^2) which would allow very thermally efficient houses to be recognised. These houses would, by applying the trends shown from the above simulations, provide thermally comfortable living even with future temperature increases.

The national building code (Building Code of Australia – BCA) has recently introduced minimum energy efficiency standards for all new residential dwellings which are aimed at lifting the average energy rating of 1.5 up to rating 3. Given the above DEROB and BERS simulation results, there will be diminishing ability for existing houses with average ratings of 1.5 and even new houses with average ratings of 3 to cope with future predicted temperature increases. This leads to the obvious conclusion that there will be an increasing mechanical energy demand for summer cooling (air conditioning) in existing and future housing to achieve thermal comfort in the face of increasing annual average temperatures.

Therefore, there is an urgent need to improve the thermal performance of new and existing houses, if possible, up to a 5 star energy rating to cope with future temperature increases. This appears to be the only way of slowing the burgeoning energy demand from residential housing, with its associated greenhouse gas pollution.

10. Conclusions and recommendations

Global warming and heat island impacts have the potential to change average climatic conditions in high lot density residential developments by up to 4 degrees Celsius. Hence, houses planned today should take account of such future temperature increase impacts. Reducing heat island impacts will directly reduce global warming effects while also providing an indirect reduction through less cooling energy being needed by the houses.

The challenges associated with warming impacts are summarised below together with recommended actions and strategies:-

1. Increasing population in south east Queensland combined with a demand for resource efficiency from infrastructure provision is resulting in new residential developments producing smaller lot sizes (widths down to 10 metres). Smaller lots will result in smaller houses which require less energy to produce and operate, especially if designed using passive principles.
2. There are energy savings from the shading advantages of closer housing on small lots if they are oriented generally north-south. The resultant small lot house design still requires thoughtful planning as does the subdivisional layout with access roads being generally east-west.
3. Smaller lots sizes results in increased housing density which leads to increased heat island impacts. These impacts can be mitigated through the use of light coloured (high albedo) surfaces (roofs, walls, roads and other paved areas) and the reduction of hard surfaces (e.g. narrowing road pavements). Minimising hard paved areas will also allow for improved ground water recharge which will assist vegetation growth.
4. Increased planting of spreading trees to shade hard surfaces with planting on the northern sides of roads have some advantages. Increased shade vegetation creates cooler micro climates but should not restrict northerly solar access to housing especially during the winter.
5. If average temperatures increase in future, houses with low energy rating will not perform well during hot summer months. This was evidenced with thermal simulations that raised average temperatures by 2 and 4 degrees Celsius. Even a 5 star house would have some difficulties in maintaining year round thermal comfort with a 4^oC rise in average summer temperatures. A 3.5 star rated house will not perform adequately in such increased temperature scenarios. It can be easily deduced that houses with ratings less than 5 will require air conditioning in the future which will result in additional global warming.
6. There is an urgent need to curb global warming. Energy efficient housing that reduces that impact is needed now and it should remain efficient even when subjected to increasing average temperatures. This should be combined with heat island mitigating efforts at the local level guided by developers, their urban designers and with the participation of their housing community.

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Appendix A: The properties of materials

The material properties used for the simulations are given in Table A.1 which are obtained from Nayak et al (1999).

Table A.1: Properties of the materials used in the simulations

Material type	Conductivity (W/mK)	Specific heat (Wh/kgK)	Density (kg/m^3)
GI sheets	50	0.13	7800
Mineral fibre	0.04	0.40	30
Earth	1.4	0.22	1300
Plain concrete	1.7	0.25	2300
Burnt clay bricks	0.82	0.24	1850
Air space	0.024	0.28	1.201

Appendix B: Details of DEROB-LTH

DEROB – LTH, which is an acronym for Dynamic Energy Response of Buildings, was originally developed at the Numerical Simulation Laboratory of the School of Architecture, University of Texas. Later, it was further enhanced at the Department of Building Science, Lund Institute of Technology (LTH), Sweden. It was validated in many studies such as Kallblad (1999) and Jayawardane (2002).

DEROB is a dynamic simulation program which utilizes generalized algorithms to simulate hourly energy performance of building structures of many generic types inclusive of passive solar buildings. The input data is of two general types, namely the building description data and environmental data. The first type includes the geometry of the space defining thermally active building elements such as walls, roof, floor and openings like doors and windows. In addition, the program can handle thermally inactive exterior shading screens which can be used to model the effect of eaves at the roof level and shading devices used over the openings. The material composition of the thermally active building elements is managed by using opaque and transparent material libraries. The effects of surface texture and colours were handled by using absorptance and emittance values of the outer surfaces. Additional input data of the first type are the orientation of the building, site, period of simulation and schedules for forced ventilation, infiltration, heating and cooling.

The second type of data includes the weather data of hourly values for ambient air temperature, direct solar insolation on horizontal surface, diffuse solar insolation on horizontal surface and the sky temperature. DEROB is capable of handling the distribution of solar radiation with considerable accuracy. Another special feature is its ability to consider solar angle dependent optical properties of single and multiple glazing assemblies.

DEROB-LTH can produce detailed output such as indoor temperature on an hourly basis, the surface temperatures of a given volume. It can also calculate the air-conditioning and heating loads and also predict the possible indoor temperatures when the plant capacities and the operational schedules are known.

DEROB simulations
In order to create the conditions given in above cases for DEROB simulations, the climatic data files required appropriate modification. For Case 1, the climatic data file based on past records was used for both temperatures and solar radiation. For Case 2, the outdoor temperature was increased by 2^{o}C. For Case 3, the outdoor temperature was increased by 4^{o}C. In both these cases, the solar radiation effects, which is unlikely to change due to global warming, were kept as the same as those based on past records.

The main simulated design features included a concrete slab as the foundation (contrary to the original design), brick walls with insulation, a ceiling at a height of 2.4 m and the windows selected for sufficient daylight and architectural requirements. The orientation of side walls of the display house was at 20^{o} to the north, but this was considered as in true north for the simulations. This house was initially modeled as a three star rated house with BERS software and then further modified to provide an energy rating of five. The additional features to achieve the 5 star rating was the inclusion of low emissivity glass for north, east and western windows and extra insulation for roof and the ceiling. The roof insulation was 50 mm of mineral wool (R1.5) with reflective foil facing the ceiling which was provided with 100 mm of bulk mineral fibre insulation (R2.5). An energy rating of 3.5 was achieved when roof insulation and low emissivity glass were removed and ceiling insulation was reduced to 50 mm.

The following passive features were included for both the rating simulations of 3.5 and 5:

1. Garage, laundry and bathroom on the western side. Garage and laundry protect the rest of the house from hot summer afternoons.
2. The living/dining rooms face north and can benefit from solar penetration during the winter months.
3. Bedrooms zoned to the east and south for thermally more comfortable conditions.
4. House close to road to allow larger rear garden space for appropriate vegetation
5. North facing windows provided with shading devices to screen the summer sun.

Using the simulation program DEROB-LTH, it was possible to create an accurate model of the house as shown in Figures 3 (a) and (b). These two figures indicate that the house was provided with a certain number of shading devices on the northern and western sides to minimise the impact of solar radiation during the summer. For the actual house given in Figure 2(a), certain modifications were made when identifying various spaces for modelling as shown in Figure 2(b), since DEROB has a maximum number of eight simulation volumes. The complicated roof arrangement was also created using the facilities provided by DEROB-LTH. The eaves were created as shading screens as were the presence of nearby houses. The effect of the pergola over the courtyard was represented by using a shading screen with a suitable value for solar radiation transmittance (15%). The climatic data used by the BERS program for Ipswich were used for Case 1. For Cases 2 and 3, the temperature values were modified.

There are other details adopted with computer simulations and they are described with the main features of the house improved up to an energy rating of five:

1. The roof consisted of light coloured Colorbond sheets with 50 mm mineral fibre insulation and reflective foil facing the ceiling. The flat ceiling below the roof is provided with 100 mm of bulk mineral fibre insulation.
2. The walls consisted of brick veneer of 110 mm thickness on outside, a layer of 50 mm (R1.5) of bulk insulation and 10 mm of gyprock mounted on a metal frame with an air gap of 70 mm inside, giving a total wall thickness of 240 mm.
3. The floor was tiled except in the bed rooms where carpeting was provided. An absorptance of 50% was adopted to indicate light coloured carpets and tiles.
4. The windows consisted of 3 -5 mm thick low emissivity glass. The reflectivity was 55% and transmittance was 20%. The emittance of the front and back was 34%. These values were specified in the manufacturer's literature.
5. The internal walls were a light colour, generating an absorptance of 40%. The external walls had an absorptance of 60% which represented the colour of bricks.

6. The number of air changes was maintained as 1 ach (air changes per hour) in order to ensure that excessive ventilation would not hide the real effects of varying the outdoor temperature. A value of 1 ach was recommended by Grade et al. (2001) to represent a weak flow rate of air which nevertheless is sufficient for the preservation of hygienic conditions indoors. A value of 0.3 ach was used by Taylor et al. (2000) in order to isolate the effects of ceiling insulation.
7. The block had a length of 31.1 m and a width of 10.5 m. This width resulted in a clearance of 1.4 m on one side boundary while the house wall stood on the other side boundary. A rear clearance of 5.0 m resulted between the house and the rear boundary of block. It was proposed that two similar houses be constructed on either side to create shading screens. This arrangement thus gives two shading screens at a distance of 1.4 m away from the house. The shading screen representing the garage was considered as shorter than that representing the wall for bedrooms. The shading effects of trees that may be located close to the house were not taken into account in any of the simulations.